SECTION 3

# Definition and Evaluation of the Problem

This section describes the expected generation, duration, and fate and transport of methane in typical municipal landfills and the potential for methane production from natural sources. This section also evaluates the potential generation, duration, and fate and transport of methane near Landfill 26. A qualitative evaluation of potential risk posed to receptors at Landfill 26 is also presented.

## 3.1 Expected Generation, Duration, and Fate and Transport of Methane in Landfills

The following subsections present summaries of the expected generation, duration, and fate and transport of methane in modern municipal landfills. These summaries are based on observations of sanitary landfills under conditions that are common today. Accordingly, these summaries establish a framework to assess Landfill 26, which is older and shallower, and contains less waste that can decompose than a modern municipal landfill. Site-specific expectations for Landfill 26 are addressed in Section 3.3 of this report.

### 3.1.1 Generation

Modern municipal solid waste landfills typically generate significant volumes of various gases during their active life and for a period of time after closure (NHDES, 1998). Most of the gas generated consists of methane and carbon dioxide, with trace amounts of volatile organic compounds. This landfill gas is generated by bacterial activity that decomposes decaying materials in the waste. In those portions of the subsurface where sufficient oxygen is present, aerobic bacteria are predominant and carbon dioxide is the principal landfill gas produced. Where oxygen is not sufficient or is not replaced, anaerobic degradation takes over, and methanogenic (methane-producing) bacteria become predominant. Because of the volume of soil typically used as cover material and the amount of moisture in modern landfills, it is typically difficult for oxygen to be adequately replaced as it is consumed.

Both aerobic and anaerobic degradation require the presence of sufficient water, with landfill gas production rates being directly proportional to the moisture content of the waste (Christiansen and Kjeldsen, 1989); in general, the more water available for degradation, the more gas will be produced.

### 3.1.2 Duration

One source suggests that methane production in a modern landfill may last from 15 to 60 years (CAPCOA, 1990). However, landfill gas can be produced as long as degradable waste remains. In arid regions and in landfills with low-permeability cover systems (especially those with geomembranes) landfill waste typically degrades very slowly because it is kept isolated from sufficient water to support the degradation process. In the other extreme, submerged waste can become completely decomposed in less than 20 years.

The period of time over which landfill gas is generated can also be affected by a site's heterogeneity. Some parts of the landfill may be moist enough to promote rapid decomposition, while other parts may not have enough moisture, and gas will continue to be generated for many years at a slow rate.

The types of wastes within the fill also influence the duration of gas generation. Generally, landfills have a variety of wastes: some that degrade rapidly, some that degrade slowly, and some that do not degrade at all. If a landfill has a higher-than-typical amount of slowly degrading wastes, such as wood, the gas will be generated at a lower rate, over a longer period.

### 3.1.3 Fate and Transport

Many mechanisms influence landfill gas fate and transport. Landfill gas generally:

- Moves from an area of high pressure to an area of low pressure (advective movement)
- Moves from an area of high concentration to an area of low concentration (diffusive movement)
- Degrades (the methane portion) in the presence of oxygen and methanotropic bacteria (biological degradation)
- Dissolves (both methane and carbon dioxide) into soil moisture and groundwater
- Adheres to moisture on soil particles (adhesive movement)

Generally, advective movement is the most significant mechanism within landfills. Landfill gas tends to vent through the surface to the atmosphere in an active landfill or in an uncapped, inactive landfill. In a landfill with a geomembrane cover, landfill gas is forced to leave areas of high pressure (within the landfill) via other routes. Landfill gas will also not migrate through saturated or nearly saturated soil. If the groundwater table is near the waste, this will create a moist soil zone that will both act as a barrier to flow and as a source of water to promote waste decomposition.

Short-term variations in barometric pressure can also cause gas to migrate from or into the landfill, because the pressure beneath the RCRA cap seeks to equilibrate with the atmosphere. This phenomenon is known as barometric pumping.

Once landfill gas has migrated beyond the boundaries of landfill waste, it will generally not migrate by advection, because it is no longer in the zone where decomposition is occurring and where pressure can build up. (In large modern landfills, the volume of gas generated can be so great that pressures can be exerted into the soil well beyond the waste limits; in these extreme cases landfill gas extraction systems are often installed even during site operation.) In most cases, landfill gas in soil adjacent to a landfill will move slowly by diffusion. Gas that migrates beyond the zone of decomposition into adjacent soil may be subject to the following effects:

- Atmospheric recharge (which can promote dilution or biological degradation)
- Gradual spreading (as gas diffuses into areas containing lower concentrations)

- Relative increase in the methane concentration (as the carbon dioxide preferentially dissolves into the soil moisture)

- Flushing (after rainfall events, as the front moves through the soil, transferring soil moisture containing gas to the groundwater, or forcing gas to move aside)

## 3.2 Methane Contribution from Natural Sources

Natural sources of methane within Bay Mud, such as the original land underlying much of Landfill 26, are generally believed to consist of:

- Original plant material remaining under the fill that may decompose
- Peat layers within the Bay Mud sequence along the bay margin may decompose

Although methane can be generated within Bay Mud, it is difficult for this methane to migrate as it is generally trapped in a water-saturated, low-permeability soil formation. Methane that might be generated in Bay Mud would be small in comparison to that generated by decomposition of organic material within the fill, because of its smaller volume. Methane in Bay Mud would also be expected to begin decomposing soon after the soil was originally deposited, at least several decades, and possibly several hundred or thousands of years ago. Therefore, it is not likely that methane generated in the Bay Mud today significantly contributes to the methane readings at Landfill 26.

## 3.3 Generation, Duration, and Fate and Transport of Methane Migration at Landfill 26

This section evaluates the generation, duration, and fate and transport of methane in Landfill 26 and is divided into two subsections: (1) generation and duration, and (2) fate and transport. The following evaluation is based on available data at the time of this report. In addition, this section presents the basis for the evaluation of mitigation approaches, as presented in Sections 4 and 5. Scheduled additional sampling may collect data that alter this conceptual model; these new data could require that both this model and the recommended approach be revised.

### 3.3.1 Generation and Duration

Landfill gas generation is unique for each landfill and it is not possible to precisely predict it. Therefore, engineers and regulators typically rely on calculations from empirical data and industry models to predict general generation trends for landfills.

Based on a 1992 landfill gas survey, the rate of methane emissions was calculated to be 55,000 cubic feet per year for Landfill 26 (WCC, 1997). For this study, CH2M HILL performed supplemental gas generation modeling and developed the following findings:

- The model predicted over its lifetime, Landfill 26 could generate a total of 295 million cubic feet of methane

- The model predicts 2,128 cubic feet of methane per day could be generated in 2001 (just under 1.5 scfm)

Figure 3-1 shows the modeled landfill gas and methane gas generation rate prepared for this study.

This modeling was performed using CH2M HILL's proprietary landfill gas generation model, using the following parameters as input:

- First year waste was placed: 1942
- Last year waste was placed: 1973
- Gas generation calculated through the year 2030
- Moisture content of waste: 55 percent
- Readily decomposable fraction of waste: 24 percent
- Moderately decomposable fraction of waste: 70 percent
- Organic fraction of total waste, wet basis: 62 percent
- Total waste volume: 151,500 cubic yards
- In-place waste density: 1,200 lbs / cubic yard
- Waste placement occurred at a uniform rate throughout life of the landfill

Additional information is provided in Appendix D.

CH2M HILL's model estimates gas generation from municipal solid waste (MSW) landfills, and has been used to size equipment for landfill gas collection and combustion facilities. The CH2M HILL model has been found to yield results similar to other landfill gas generation rate estimation models reported in literature (CH2M HILL, 1998d).

The findings of both the WCC calculations and CH2M HILL modeling yield relatively low landfill gas generation rates, which are consistent with the size and age of this landfill.

As previously discussed, landfill gas typically consists of both carbon dioxide and methane under anaerobic conditions. It is unclear how much of the degradation in Landfill 26 is occurring aerobically versus anaerobically, but there are several factors that, under current conditions, would favor anaerobic decomposition:

- The fairly high and fluctuating water table means that underlying and adjacent soils stay moist and restrict the recharge of atmospheric oxygen

- The geomembrane cap is not gas permeable, and further restricts the recharge of atmospheric oxygen

- The age of the waste suggests that most of the internal oxygen would have been consumed by decomposition long before this time

Because these factors favor anaerobic decomposition, and anaerobic decomposition produces methane and carbon dioxide, it is reasonable to assume that methane will continue to be generated as long as landfill gas is generated at this site.

Waste disposal at this site reportedly occurred between the early 1940s and the early 1970s, meaning that the waste in the landfill has been in place for more than 20 years. Based on previous investigations (34 trenches [WCC, 1987]) it is also apparent that the distribution of waste types varies widely. As a result, the location of decomposable materials could be scattered in discrete locations throughout the landfill footprint.

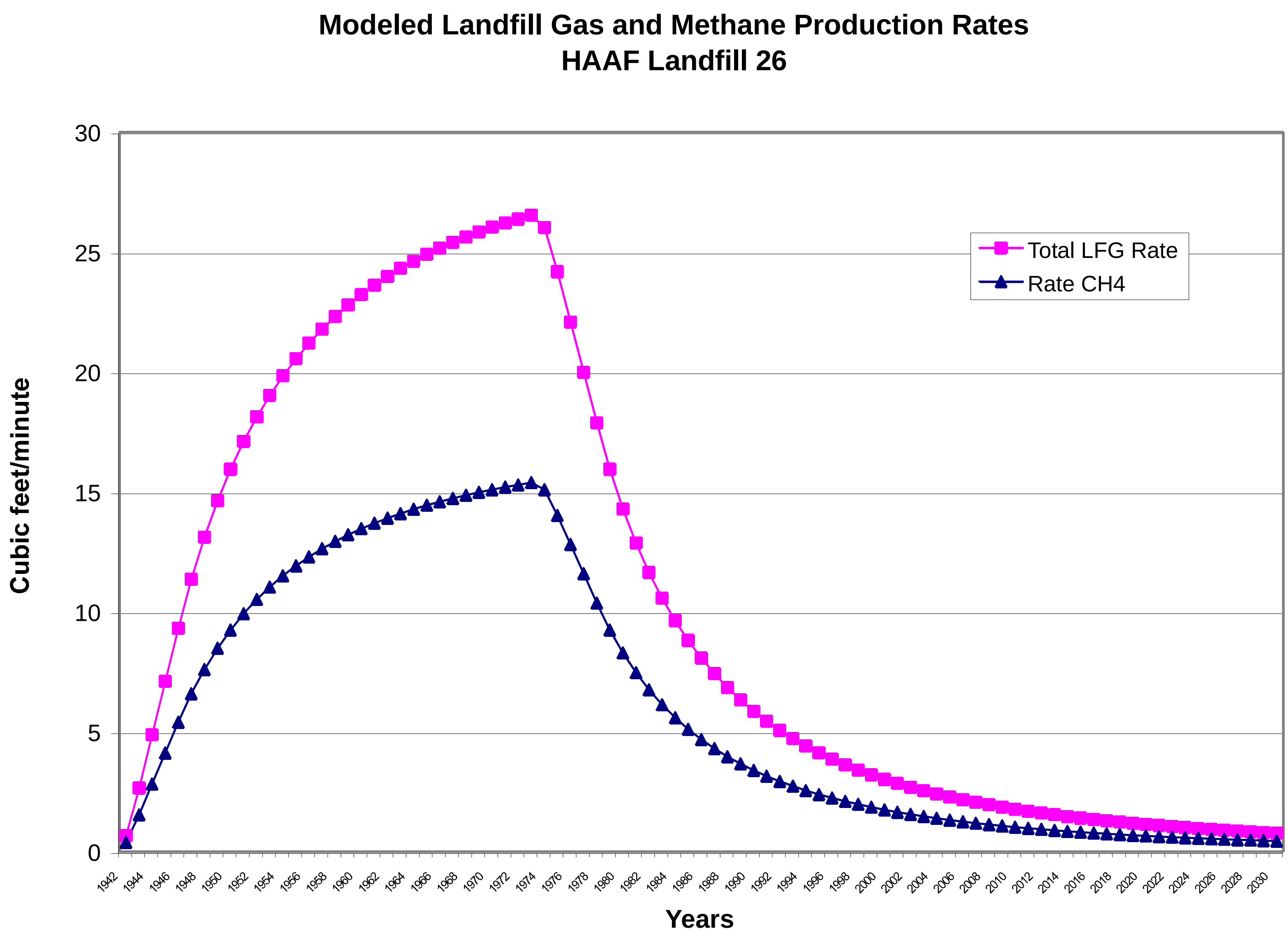



**Figure 3-1**
**Modeled Landfill Gas Generation**
Hamilton Army Airfield
Novato, California

CH2MHILL

It has been reported that construction materials, such as wood and wallboard, were the primary wastes disposed of at the landfill, suggesting that degradation will generally be slow. Wood, in particular, is expected to degrade slowly, resulting in small amounts of landfill gas produced over a longer period of time. Therefore, it is not clear how much longer landfill gas will continue to be generated in Landfill 26, but it is reasonable to consider that it could be produced for decades.

### 3.3.2 Fate and Transport

Methane appears to be migrating intermittently in soil gas within the buffer zone surrounding Landfill 26 in the vicinity of GMP-5, GMP-8, GMP-9, and the area around GMP-12 and GMP-13. The Draft Landfill Gas Migration Study (ITSI, 2000a) provides a set of mechanisms believed to account for detected methane. These mechanisms include:

- Location
- Depth of the landfill cap membrane relative to the water table
- Adjacent soil type
- Proximity of subsurface trenches backfilled with relatively porous material

Specifically, the ITSI report concluded that:

- The methane observed near GMP-13 is interpreted to have been released during a limited seasonal opening between the water table and the landfill cap membrane, and to have migrated through zones of higher conductivity. Specifically, methane has only been detected in GMP-5 and nearby direct-push probes in the months of September, October, and November, corresponding to the seasonal low water table (see Figure 2-15). In direct-push probes adjacent to probe GMP-12, the highest concentrations were detected in late November and December.

- The methane observed near GMP-8 and GMP-9 was likely being released into the relatively sandy soil adjacent to the landfill, below the RCRA cap membrane, and above the water table. In these probes and adjacent direct-push locations there appears to be some seasonal influence. The highest concentrations are seen in late summer and fall, with lower concentrations or non-detection values observed before and after these periods.

- The methane observed in GMP-5 was found in 2000 only during September and October, while in 1995-1996 it was observed in June and September. In direct-push probes near GMP-5, methane was detected in only one location (in October), and this detection indicates the potential for subsurface trenches to transport landfill gas.

Although these descriptions are plausible, the precise release mechanisms (i.e., the specific roles of the water table and the landfill cap during the summer and fall) cannot be verified. Understanding these mechanisms through further investigations would provide greater certainty in the development of the final design for any remedial measure. The available data confirm that methane can and does occur in the buffer zone at certain locations, at least during specific months of the year. However, some of the existing probes could not be sampled when the groundwater level was higher than the screened interval of the well. The installation and sampling of new probes should provide useful information on the seasonal detection of methane in the buffer zone and the release mechanisms.

The currently available data suggest that the precise duration of these releases and the persistence of methane in the subsurface are not known. The data collected in GMP-5, GMP-8, GMP-9, and GMP-13, as well as nearby direct-push samples, together with the top-of-probe-screen height and water levels measured in these areas, test the hypothesis of whether soil gas results from the probes are influenced by the rising water table. Based on the records of date from the summer and fall of 2000, there appear to be two prevailing conditions:

- In the vicinity of GMP-5 and GMP-13, the methane releases appear to be of limited duration, because the methane is first detected at a maximum and then the concentrations decay. These decays suggest that in the absence of a continuous release, natural attenuating mechanisms remove the methane with a half-life of 10 to 30 days.
- Near GMP-8 and –9, the methane appears to be released over a longer period in the summer and fall, and the concentrations do not follow a simple decay, but appear to abruptly decline in December. The monitoring record to date does not allow a high level of confidence regarding the seasonality of the releases in this area.

In addition to the lateral migration of methane gas, the USACE has conducted studies on the presence and migration of dissolved methane in groundwater (ITSI, 2001). These studies have found dissolved methane in locations generally corresponding to GMPs –8, -9, -12, and –13. Because the detections near GMP-13 are also generally upgradient of the landfill, the USACE is currently conducting additional studies to verify whether the landfill is the source of the detected methane near GMP-13 and to identify the responsible migration mechanisms. Upon completion of these studies, the USACE expects to complete an assessment of the need for remedial measures for groundwater, if any.

## 3.4 Qualitative Evaluation of Risk

The risk of landfill gas migrating to adjacent property is based on the potential that methane will combust at concentrations between 5 percent and 15 percent, in an atmosphere containing at least 10 percent oxygen, and in the presence of a spark or heat source. The components involved are:

- The rate at which methane is generated
- The migration of the methane from the source to a receptor
- The accumulation of methane in a zone near a receptor

Each of these factors is presented and evaluated qualitatively in the following text.

For the purposes of this evaluation methane is postulated to pose *potential* risks to humans and structures through its presence in the vapor phase and as dissolved methane in groundwater. Methane in vapor phase may pose a hazard if it migrates through soil or utility trenches and collects in buildings, subsurface vaults, buried utility conduits and pipes, and the like. Dissolved methane in groundwater can migrate with groundwater, and if it flows into a coarse-grained soil, such as the backfill of a utility trench, can off-gas methane into the soil atmosphere above the water.

## 3.4.1 Rate of Methane Generation

As described previously, Landfill 26 is estimated to generate 295 million cubic feet of methane during its generating lifetime. CH2M HILL's value is based on the assumptions listed in Section 3.3.1. This model estimated Landfill 26 can generate 2,128 cubic feet of methane per day in the year 2001, 548 cubic feet per day in the year 2030, and 213 cubic feet per day in the year 2060. These methane generation rates correspond to approximately 0.2 to 1.5 cubic feet per minute.

To put this value in perspective, it is not uncommon for modern municipal landfills to generate 2,000 to 3,000 cubic feet per minute of landfill gas (typically 50 percent methane), or approximately 1,500 times as much as is modeled to be generated in 2001 and 15,000 times greater than modeled in 2060 for Landfill 26. This is consistent with the age of this landfill, its contents, and volume.

In any case, it is important to recognize that methane generation potential does not equate directly to risk. The methane must be able to escape from the landfill, persist in the surrounding soil, migrate laterally without escaping through the ground surface, and accumulate in a zone near a receptor. These factors are addressed in the following sections.

## 3.4.2 Methane Migration

The migration potential of methane from Landfill 26 is a function of the opportunity for methane to exit the landfill and to migrate along subsurface flow pathways. The following subsections describe the potential of each factor with regard to Landfill 26.

### 3.4.2.1 Opportunities for Exiting LF26

Methane has opportunity to migrate from the landfill into adjacent soil via two principal mechanisms: gas migration and groundwater migration.

Landfill gas appears to be trapped within the area below the landfill cap when the water table is higher than the base of the landfill cap. Landfill gas is judged to be allowed to exit when the water table, and residual soil moisture associated with the capillary fringe, fall beneath the cap. As displayed in Figure 2-13, the most likely time for this to occur appears to be in the late summer and fall. Vapor monitoring data supporting this hypothesis were previously discussed in Section 3.3.2.

Available geologic data were reviewed and are summarized here to describe the locations along the landfill perimeter where the gap between the water table and the landfill cap could form. Figure 3-2 is a reference figure of the locations of cross sections. Figures 3-3 through 3-6 show various cross sections and demonstrate the following interpretations:

- In some areas, the liner is above the groundwater all year long
- In some areas, the liner is below the groundwater all year long
- In some areas the gap occurs only at certain times of the year

There must be a greater gas pressure within the landfill than in adjacent soil for gas to exit the landfill by advective transport. Only one series of landfill pressures was available for this study; pressures within the landfill are discussed as follows.

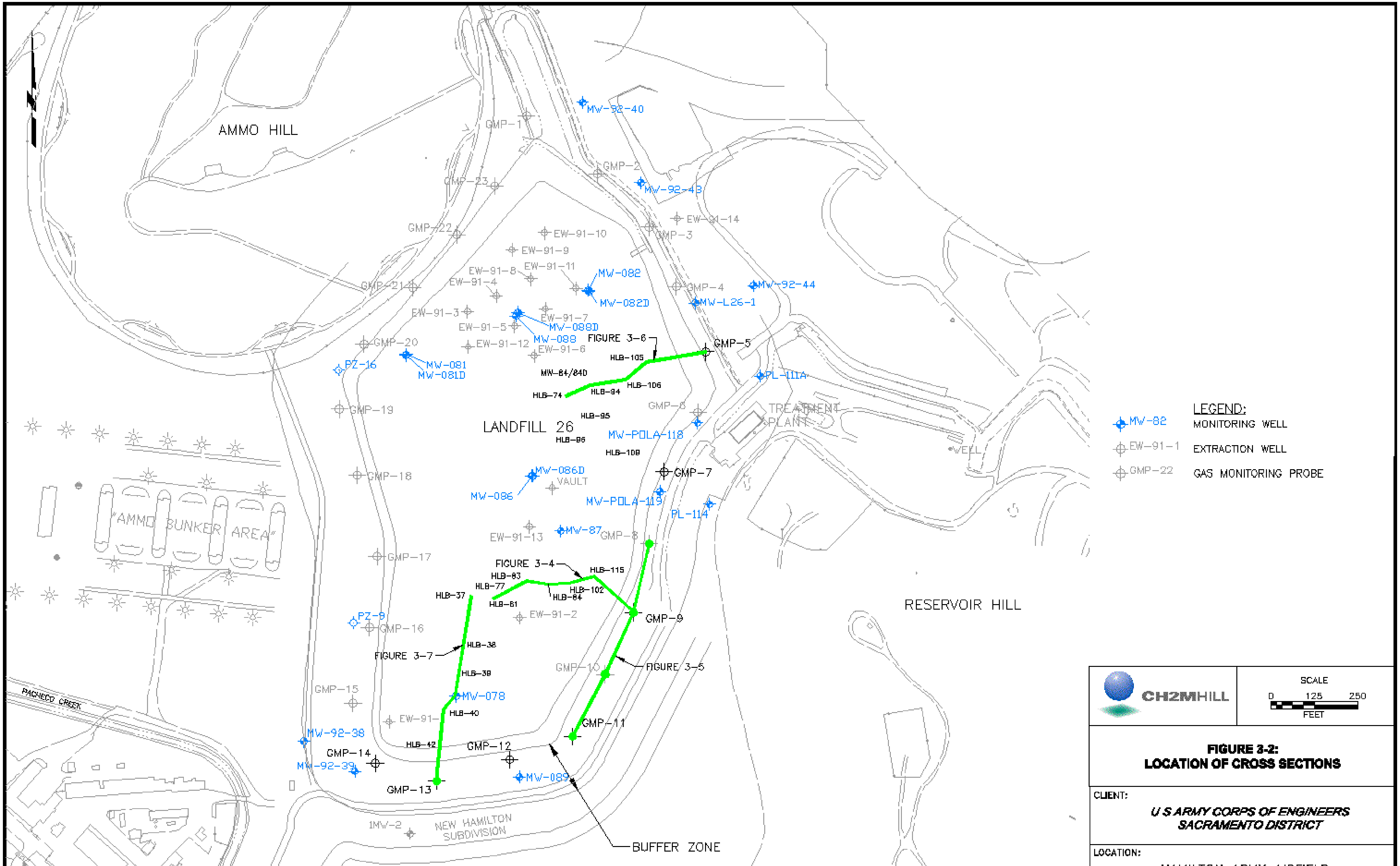
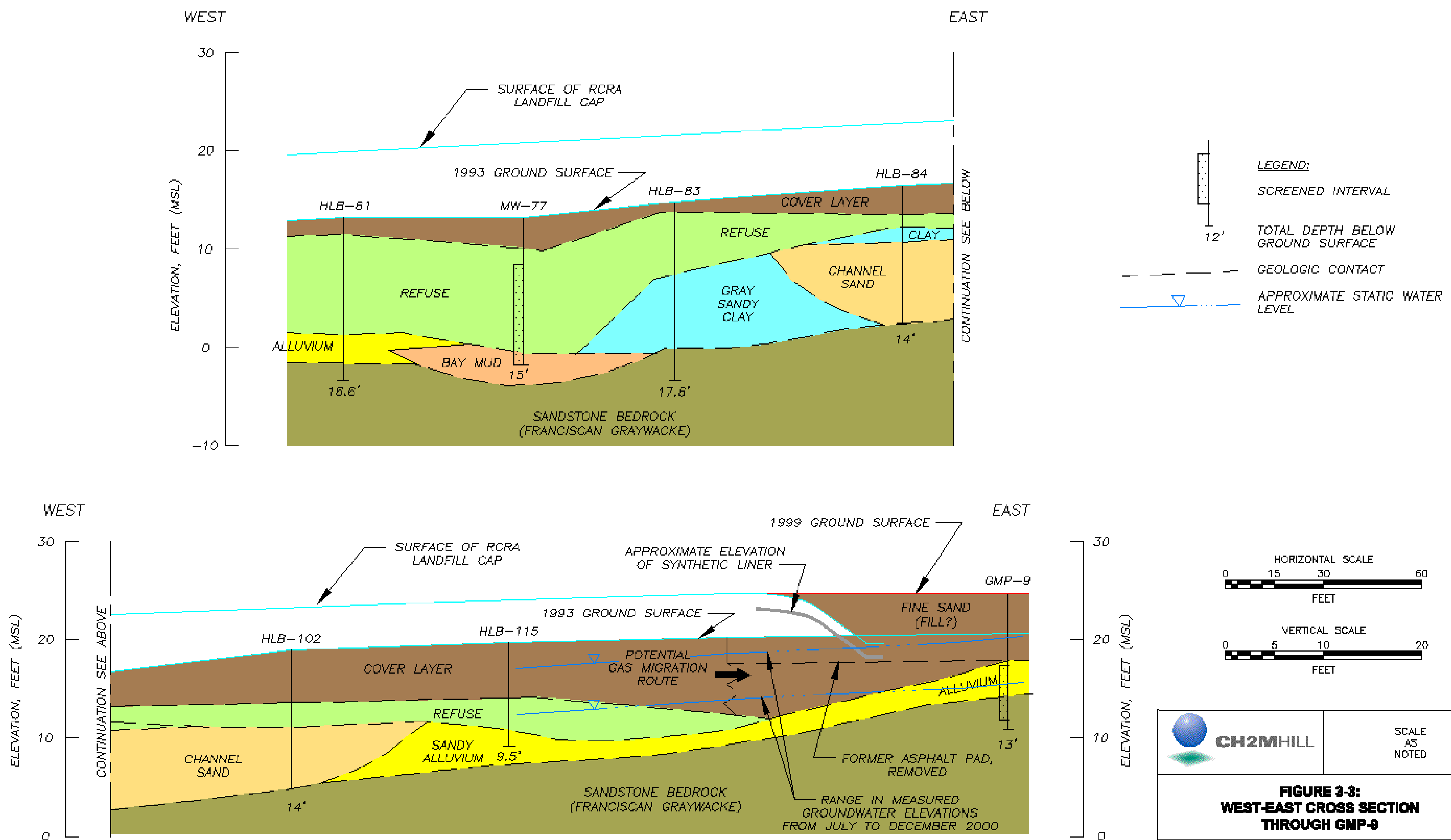



**FIGURE 3-2:**
**LOCATION OF CROSS SECTIONS**

CLIENT:
*U S ARMY CORPS OF ENGINEERS*
*SACRAMENTO DISTRICT*

LOCATION:
*HAMILTON ARMY AIRFIELD*
*NOVATO, CALIFORNIA*

**Source:** ITSI **Innovative Technical Solutions, Inc., 2001**

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SCALE AS NOTED

**FIGURE 3-3: WEST-EAST CROSS SECTION THROUGH GMP-9**

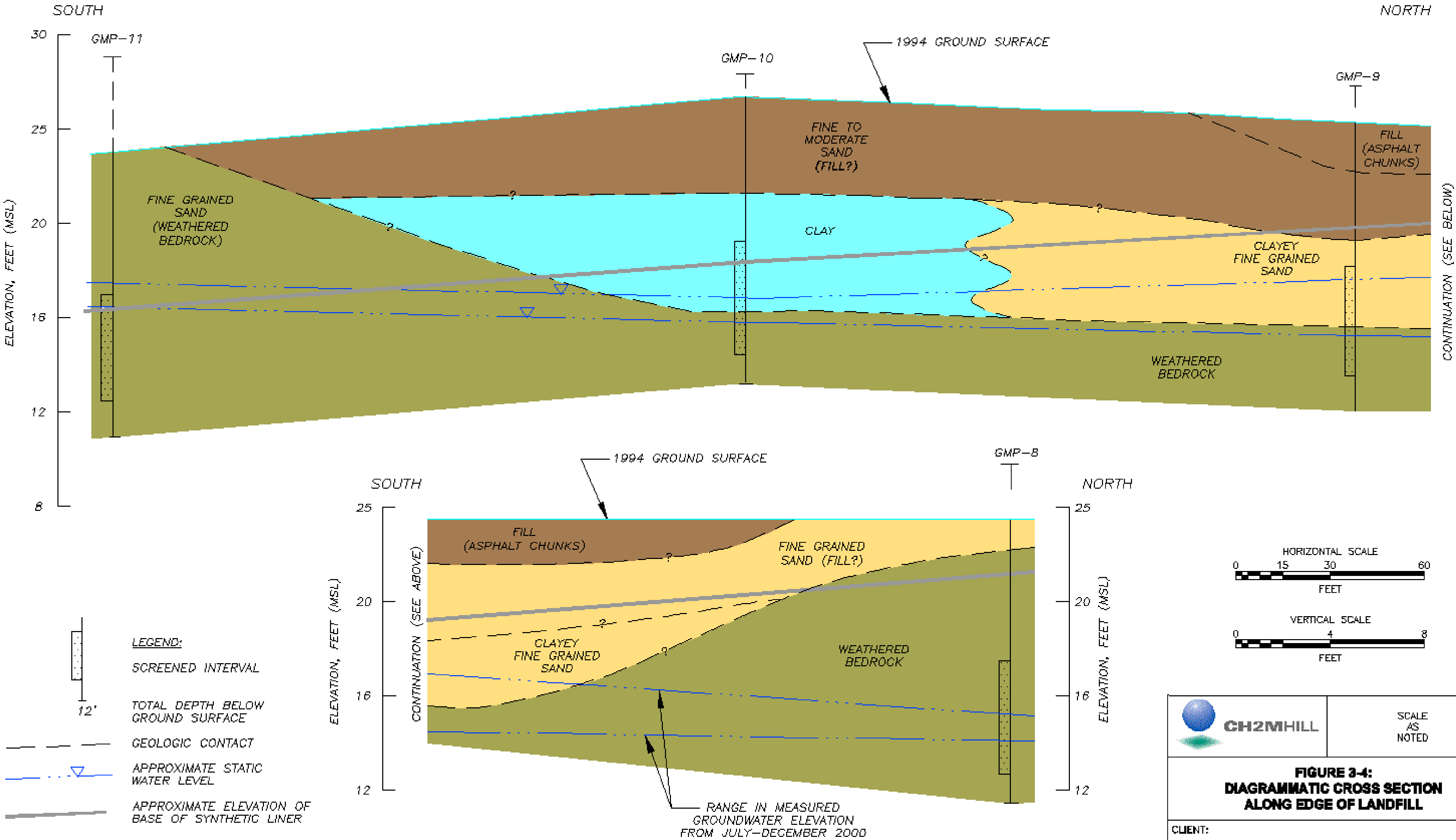
CLIENT:

*U S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT*

LOCATION:

HAMILTON ARMY AIRFIELD
NOVATO, CALIFORNIA

**Source:** ITSI Innovative Technical Solutions, Inc., 2001




CH2MHILL

SCALE AS NOTED

**FIGURE 3-4: DIAGRAMMATIC CROSS SECTION ALONG EDGE OF LANDFILL**

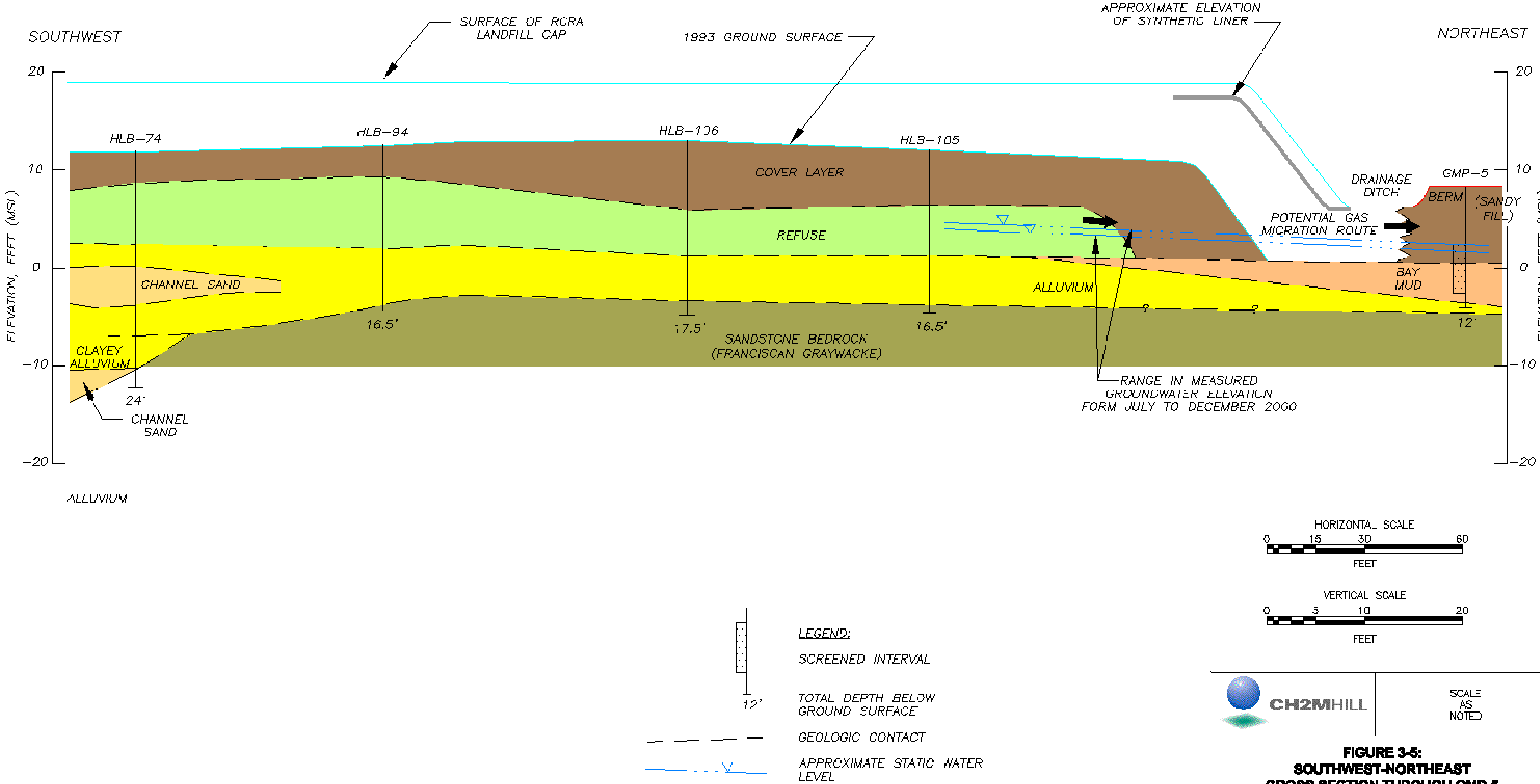
CLIENT:

*U S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT*

LOCATION:

HAMILTON ARMY AIRFIELD
NOVATO, CALIFORNIA

**Source:** ITSI **Innovative Technical Solutions, Inc., 2001**




Source: ITSI Innovative Technical Solutions, Inc., 2001

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SCALE AS NOTED

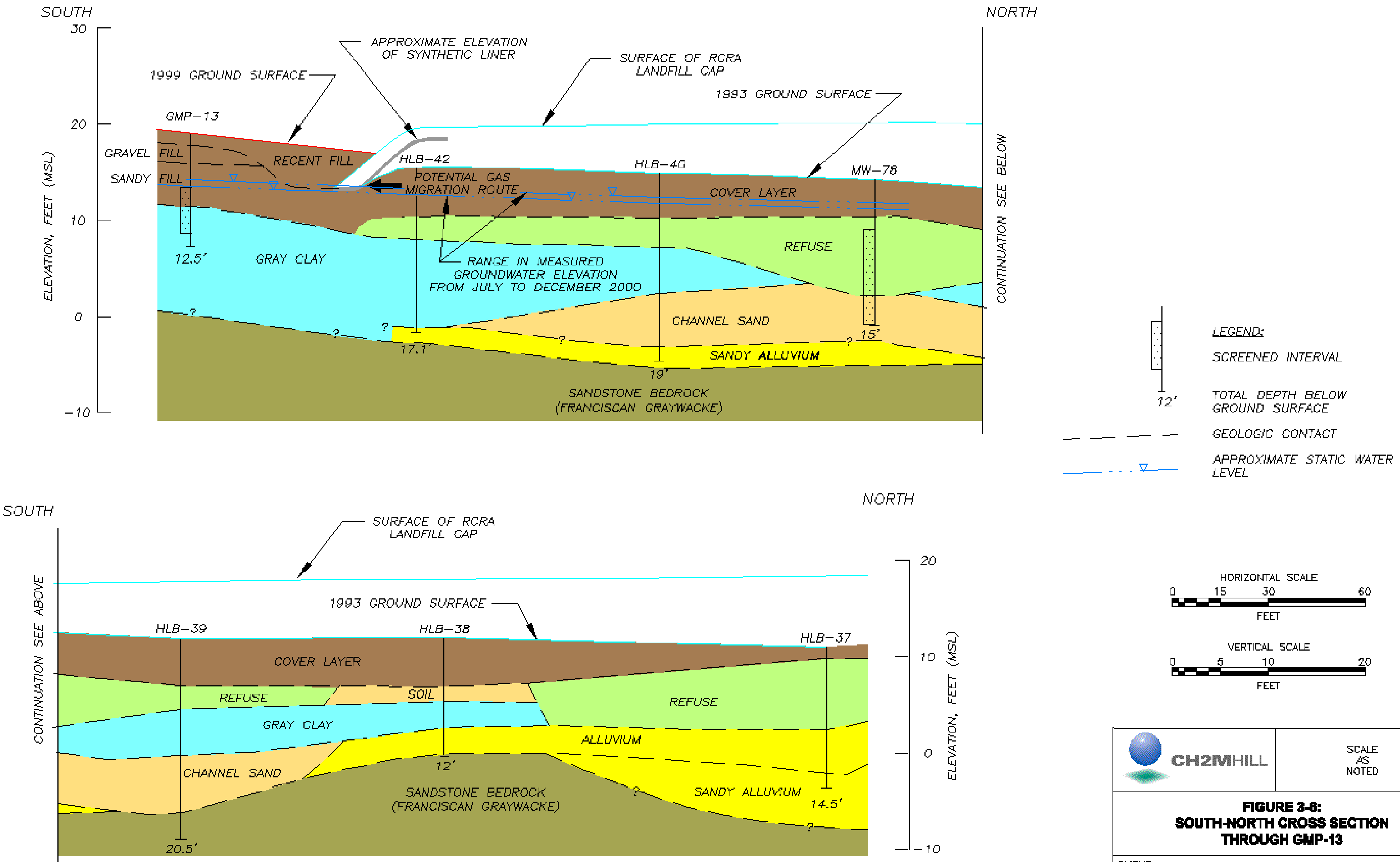
**FIGURE 3-5: SOUTHWEST-NORTHEAST CROSS SECTION THROUGH GMP-5**

CLIENT:

*U S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT*

LOCATION:

HAMILTON ARMY AIRFIELD NOVATO, CALIFORNIA




CH2MHILL

SCALE AS NOTED

**FIGURE 3-6: SOUTH-NORTH CROSS SECTION THROUGH GMP-13**

CLIENT:

*U S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT*

LOCATION:

HAMILTON ARMY AIRFIELD NOVATO, CALIFORNIA

**Source: ITSI Innovative Technical Solutions, Inc., 2001**

During November and December 2000, pressure readings were taken at 19 points within Landfill 26. None of the points exhibited pressures greater than atmospheric pressure, suggesting that pressure within the landfill is not likely to be a significant driver in the migration of methane.

Seasonal effects may influence pressure readings. Groundwater temperature in the winter has been measured to be lower than the rest of the year. This may affect the rate of gas production by anaerobic bacteria which are sensitive to temperature. Also, according to the ideal gas law, gas pressure can decrease as temperature decreases. These factors could have contributed to the negative pressures measured in November and December 2000. The negative pressure measurements, may also have been caused by groundwater level fluctuations that affected the internal pressure in the gas probe or immediately surrounding soil pore space. If so, it is possible that different pressure readings, including, positive pressure values, could be obtained during the spring and summer months. Additional data would be required to test this hypothesis.

### 3.4.2.2 Subsurface Flow Pathways

Lateral migration of landfill gas from within the landfill can only occur under the outer edge of the landfill cap, and only when the groundwater table is sufficiently below the cap. The lithology adjacent to the edge of the cap in the buffer zone is likely to significantly influence the potential for migration of the landfill gas.

As opposed to gas migration, dissolved methane in groundwater may only migrate downgradient (with the flow direction of the groundwater). The groundwater gradient at Landfill 26 generally flows toward the west-northwest beneath most portions of the landfill, and to the north and northeast in the northeastern portion of the landfill. Figure 2-13 shows the groundwater elevations within Landfill 26. Because of the dominant gradient, the migration of dissolved methane in groundwater toward the housing development is strongly limited. However, dissolved methane has been reported in groundwater south of the landfill cap. The USACE is conducting additional studies to investigate the presence of dissolved methane in this area.

#### Local Geology

Subsurface soils with high permeabilities have been found in certain locations adjacent to the edge of the landfill. The *Draft Landfill Gas Migration Study* (January 2001, ITSI) refers to these conductive zones as channel sands, which consist of greater than 25 percent medium-grained or coarser sand and all gravel beds.

Each of five geologic units (Bay Mud, bedrock, clay, alluvium, and channel sands) is present adjacent to the edge of the landfill in one or more locations. Bedrock is located along the east-central edge, Bay Mud along the northwestern and northeastern edges, gray clay along the southeastern edge, channel sands along part of the eastern edge (near GMP-8 and GMP-9), and alluvium along part of the northeastern edge and much of the south eastern landfill boundary (ITSI, 2001). As described in Section 3.3.2, the location of these units is believed to enhance or restrict the migration of methane in different portions of the landfill.

#### Utility Trenches

Utility trenches can be a pathway for methane migration by: acting to redirect methane gas, if the trench intercepts methane in the vadose zone; acting as a conduit for groundwater containing dissolved methane, if the trenches lead downgradient from the landfill, and utility trenches typically contain coarse-grained backfill, which provides a high permeability flow channel for both soil gas and groundwater, and promotes the off-gassing of dissolved methane into vapor phase. The combination of these factors makes the identification of potential subsurface utilities important to address potential risk.

The Hamilton Meadows Housing Development is located south of Landfill 26, approximately 150 feet upgradient of the landfill-capped portion, at the perimeter of the buffer zone. The subsurface utilities include the construction of trenches for an 8-inch-diameter sanitary sewer line, a 36-inch-diameter storm drain line, a water main, Pacific Bell Telephone line, PG&E gas and electric lines, and a cable television line. These utilities were installed in the roadway, with laterals to each home. In addition to subsurface utility trenches, gravel road pack may allow for enhanced subsurface, unsaturated zone, and soil gas migration. Figure 3-7 presents a view of the approximate location of the proposed homes and their associated underground utilities.

According to the Hamilton Meadows Improvement Plan (CBG, 1999), these underground utilities generally run parallel and under the residential streets adjacent to the sidewalks. Laterals from the main lines for each of the subsurface utilities run approximately 4 feet below grade, as necessary, to each house. These lateral lines are the lines that will be closest to the Landfill 26 buffer zone.

The distance of the utilities from the landfill suggests these are not likely to collect explosive concentrations of methane, based on current data. More sample data are being collected to verify this interpretation.

Although groundwater intersecting a utility trench is recognized as potential migration risk, the Hamilton Meadows Housing Development trenches are typically upgradient, so are not judged to be a likely receptor of dissolved methane in groundwater. The additional studies being conducted by USACE are addressing whether dissolved methane means the south end of the landfill represents such a risk.

Downgradient from Landfill 26 there is one identified subsurface utility. The groundwater extraction system at Landfill 26 includes a subsurface trench leading to the groundwater treatment facility from the wells, and may be acting as a collector of landfill gas in the northeastern vicinity of the landfill. One direct-push probe installed near GMP-5, and this trench did detect methane, as reported in Section 3.3.2. Figure 2-6 shows the groundwater extraction conduit throughout the landfill and its exiting point from the landfill near GMP-5.

### 3.4.3 Accumulation of Methane in Zones Near Receptors

Risk to recreational users will exist if there is human access to confined spaces where methane could accumulate at explosive levels (such as vaults, storm drains, or manholes adjacent to the edge of the RCRA cap). Access to these locations and to gas vents should be restricted.

Risk to residential homes will exist if methane is present at explosive levels (5 percent) within residential property boundaries. To date, methane has not been detected on residential property at explosive levels. However, methane has been occasionally detected

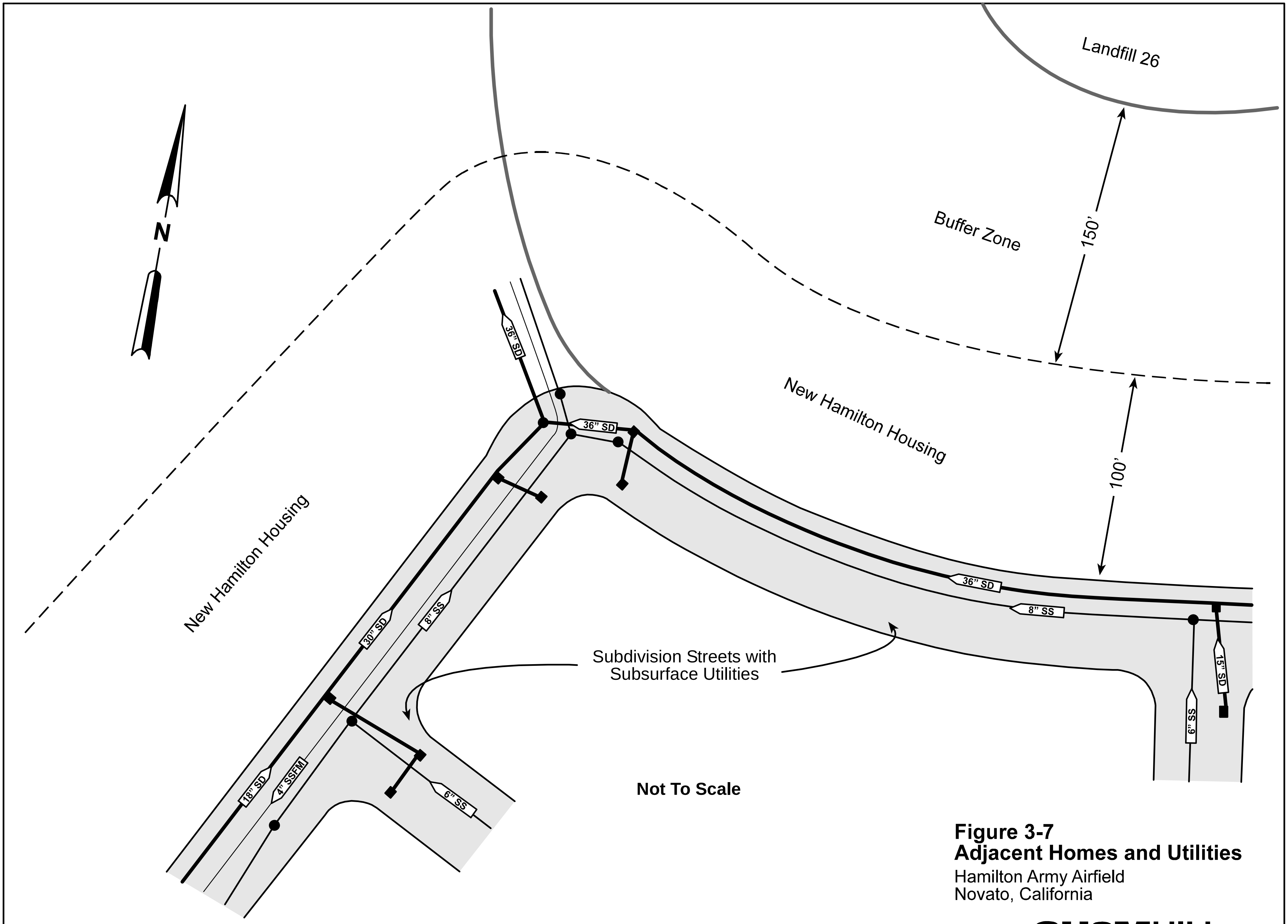



**Figure 3-7**
**Adjacent Homes and Utilities**
Hamilton Army Airfield
Novato, California

CH2MHILL

163181.12.MS homes_utilities.FH8 3-28-01 dash at levels above 5 percent in the vicinity of GMP-5, GMPs -8 and -9, and GMP- 12 and -13 within the buffer zone. USACE is currently installing additional soil gas probes along the property boundary of the residential development and the landfill buffer zone. Sampling results from the new and existing soil gas probes will help define the presence and movement of methane within the buffer zone and the potential for methane to migrate past the buffer zone at explosive levels.

## 3.5 Methane Risk Summary

Landfill 26 produces methane gas at a relatively low rate consistent with its size, contents, and age. Methane produced by the landfill appears to be migrating intermittently in the buffer zone surrounding the landfill as a function of location, depth of the cap, location of geomembrane relative to the water table, soil type, and proximity of subsurface trenches. Methane is occasionally detected in the buffer zone at levels above 5 percent. Methane has not been detected beyond the buffer zone or on residential properties at levels above 5 percent.

Methane released from the landfill is not expected to pose a risk to recreational users if human access to confined spaces where methane could accumulate is controlled. Methane released from the landfill is not expected to pose a risk to residences adjacent to the landfill buffer zone if methane is controlled within the buffer zone and does not reach residential properties at explosive levels. Additional studies being conducted by USACE will further characterize the presence of methane in the buffer zone and the potential for methane to migrate beyond the buffer zone at explosive levels.

Remedial options that control methane within the buffer zone and effectively monitor for the presence of methane within the buffer zone and adjacent property boundaries can be expected to mitigate the potential risk for methane to migrate and reach residential receptors at explosive levels. Remedial options that control methane within confined areas such as utility vaults or trenches within the buffer zone can be expected to mitigate the potential risk for methane to accumulate at explosive levels within structures at the landfill.

## 3.6 Evaluation of Presence and Migration of Volatile Organic Compounds in Soil Vapor

The Gas Monitoring Probes were monitored for four fixed gases and 59 volatile organic compounds (VOCs) at various times between September 1999 and December 2000. During this time, quantifiable concentrations were detected of 28 VOCs, all at relatively low levels. The data collected are summarized in Table 3-1.

In this table the maximum and mean concentrations quantified are compared to an air toxicity criterion that would normally apply to aboveground exposures. This comparison is made for the purposes of putting the detected values in the context of whether the low levels detected could pose a significant risk. Based on the data collected, the data appear to be generally 1/10,000 of the air toxicity criterion or less, indicating that the VOCs are unlikely to govern the selection or location of remedial measures for subsurface vapors at this site.

**TABLE 3-1**
Summary of Detected VOCs

| Compound | Probes in Which Compound was Detected* | Number of Detections * | Maximum Concentration Detected* (ppbV) | Geometric Mean of Detections* (ppbV) | TLV** (ppbV) |
|---|---|---|---|---|---|
| Benzene | 3, 5, 6, 7, 8, 9, 11, 12, 13, 15, 18, 23 and DP samples near 5, 10, 12 | 22 | 5.7 | 0.9 | 10,000 |
| Methylene Chloride | 3, 5, 8, 11, 14, 16, 18, 23 and a DP sample near 10 | 17 | 15 | 4.8 | 50,000 |
| Freon 12 | 3, 5, 8, 11, 18, 23 | 11 | 3.3 | 0.9 | 1,000,000 |
| Chloromethane | 3, 8, 11, 18, 23 | 9 | 0.9 | 0.7 | 50,000 |
| Chloroethane | 3, 14, 18, 23 | 4 | 1.1 | 0.4 | 1,000,000 |
| Freon 11 | 3, 8, 11, 18, 23 | 8 | 0.5 | 0.3 | 1,000,000 |
| Chloroform | 3, 23 and DP sample near 5 | 4 | 0.5 | 0.3 | 10,000 |
| Trichloroethene | 3, 5, 8, 11, 14, 18, 23 | 11 | 4.3 | 1.3 | 50,000 |
| Toluene | 3, 5, 8, 11, 12, 14, 18, 23 and DP samples near 5, 10, 12 | 16 | 9 | 4.8 | 50,000 |
| Tetrachloroethene | 3, 23 | 3 | 1.1 | 0.5 | 25,000 |
| Ethyl Benzene | 3, 5, 8, 11, 14, 18, 23 and DP sample at 10 | 13 | 1.2 | 0.8 | 100,000 |
| m,p-Xylenes | 3, 5, 8, 11, 14, 18, 23 and DP samples at 5, 10 | 14 | 4 | 2.1 | 100,000 |
| o-Xylene | 3, 5, 8, 11, 18, 23 and DP sample at 10 | 12 | 1.3 | 0.8 | 100,000 |
| Styrene | 3, 8, 18, 23 and DP sample at 10 | 7 | 0.5 | 0.4 | 20,000 |
| 1,3,5-Trimethylbenzene | 3, 8, 11, 12, 18, 23 and DP samples at 5, 10, 12 | 10 | 2.2 | 0.6 | — |
| 1,2,4-Trimethylbenzene | 3, 5, 8, 11, 12, 14, 18, 23 and DP samples at 5, 10, 12 | 16 | 2.7 | 1 | — |
| 1,4-Dichlorobenzene | 3 | 1 | 0.2 | 0.2 | 75,000 |
| 1,2,4-Trichlorobenzene | 3 | 1 | 0.2 | 0.2 | 5,000 |
| Acetone | 3, 5, 8, 11, 12, 14, 18, 23 and DP samples at 5, 10, 12 | 16 | 74.6 | 23.2 | 500,000 |
| Carbon Disulfide | 3, 5, 8, 11, 18 and 23 | 9 | 4 | 1.7 | 10,000 |
| 2-Propanol | 3, 5, 8, 11, 14, 18 and 23 | 13 | 220 | 65.5 | 400,000 |
| Hexane | 3, 5, 8, 11, 14, 18, 23 and DP sample at 10 | 10 | 8 | 2.6 | 50,000 |

**TABLE 3-1**
Summary of Detected VOCs

| Compound | Probes in Which Compound was Detected* | Number of Detections * | Maximum Concentration Detected* (ppbV) | Geometric Mean of Detections* (ppbV) | TLV** (ppbV) |
|---|---|---|---|---|---|
| Cyclohexane | 8, 18, 23 | 3 | 2.9 | 1.6 | 300,000 |
| 1,4-Dioxane | 18 | 1 | 1.7 | 1.7 | 25,000 |
| 2-Hexanone | 3 | 1 | 1 | 1 | 5,000 |
| 4-Ethyltoluene | 3, 23 | 2 | 0.7 | 0.7 | N/A |
| Ethanol | 3, 5, 8, 11, 14, 18, 23 | 12 | 30 | 7.5 | 1,000,000 |
| MtBE | 14, 18 | 3 | 1,300 | 95.2 | 40,000 |

[a] NIOSH value (National Institute for Occupational Safety and Health), US Department of Health and Human Services. All other values in this column are threshold limit values (TLVs) from ACGIH (American Conference of Government Industrial Hygienists).
*Compounds were considered to be present when the detected value was above the quantification limit for the analysis.
** TLV – Threshold limit value. An estimate of the average safe airborne concentration of a substance in representative conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effects. Published by the American Conference of Government Industrial Hygienists (ACGIH).

These data were also evaluated to assess whether there is a correlation between the release of methane at the landfill and the presence of VOCs in soil gas probes at the landfill. This review consisted of identifying sampling events where VOCs were quantifiably detected and methane was also analyzed. The review identified 26 data sets in which one or more of 28 VOCs were quantified and methane results available from the same gas monitoring probe sample (see Table 3-1). The 26 data sets where then examined by comparing the VOCs with the highest concentrations (a total of 10) for each sample event to the corresponding methane value for that sample event. This comparison showed virtually no correlation between methane concentrations and VOC concentrations; elevated levels of methane in a gas monitoring probe did not correspond to elevated levels of VOCs in the same probe (and vice versa) in 95 percent of the sample pairs.

If the VOCs presence in the soil gas probes were related to the generation, release and migration of methane, a much stronger correlation between the detection of methane and the detection of VOCs would have been expected. Because the strong correlation is not present based upon available data, another mechanism could be responsible for the detection of these trace levels of VOCs in the gas monitoring probes (such as diffusion from the landfill).